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Operational Factors Influence Spray Drift and Deposition from Helicopters

I. W. Kirk and W. C. Hoffmann

Agricultural Research Service, USDA, 2771 F&B Road,
College Station, Texas 77845-4966 USA

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Abstract. *A field study was conducted to determine influences of boom length and spray droplet size on effective swath width and spray drift from Hiller UH-12E and Bell OH-58 helicopters. Boom lengths of 75% and 100% of rotor diameter and droplet sizes of 400 µm (Medium (M) spray with 2.5% of spray volume in droplets less than 100 µm diameter) and 1000 µm (Extremely Coarse (XC) spray with 0.5% of spray volume in droplets less than 100 µm diameter) were used for treatment conditions. Results of the study show that boom lengths of 75% reduce effective swath width when compared to 100%, for the droplet sizes and operating conditions of this study. The 100% boom length results in increased downwind drift. The XC droplet spectrum reduces downwind spray drift and deposition, compared to the M droplet spectrum. This study provides helicopter operators with operational guidelines for boom length and spray droplet size to optimize swath width and mitigate spray drift from helicopter applications of crop production and protection products.*

Keywords. Aircraft, helicopter, nozzles, drift, spray, droplet size, boom length, swath width

Introduction

Fixed-wing aircraft have been used for aerial application since 1921 and predominate in the aerial application industry. Helicopters – also known as rotorcraft or rotary-wing aircraft – were first demonstrated for aerial application of crop production and protection materials in 1945. Helicopters have experienced continued growth in specialty uses such as forestry, high-value crops, rights-of-ways, and other applications where constraints exist on maneuverability or other factors where helicopters have an advantage over fixed-wing aircraft (Anon., 1998). Helicopter operators, like fixed-wing operators, are concerned about spray drift or spray deposits on non-target areas. The Environmental Protection Agency recognized, in proposed product label language for controlling spray drift, that helicopters may be less prone to spray drift in that guidelines for boom lengths for helicopters were set at 90% of rotor-span, compared to 75% of wingspan for fixed-wing aircraft (Mulkey, 2001). However, some operators believe, because of the relative locations of wing or rotor-tip vortices and spray booms on helicopters as compared to fixed-wing aircraft, that boom lengths exceeding 90% of rotor-span would not adversely affect spray drift from helicopters. There is continuing interest from all segments of the aerial application industry in better understanding the sources and causes of spray drift and in implementing effective drift mitigation practices, while also maintaining efficiency of operations and efficacy of the applied materials.

Spray droplet size has been recognized as the most important variable that aerial operators can control to mitigate spray drift from the application target site. Sprays with coarse droplet spectra drift less than sprays with fine droplet spectra. Boom height and aircraft boom length are other important variables that influence spray drift (Anon., 1997). The pilot controls boom height, height of spray release, or height of flight with considerations for effectiveness and safety of the operation. Droplet size and boom length are primarily established in hardware and are generally fixed for a given operation. We selected these hardware variables in this study to determine their influence on spray drift and swath width.

Objective

The objective of this study was to determine the influence of boom length and spray droplet size on spray drift and effective swath width for helicopters.

Materials and Methods

A two-component field study was conducted to determine the effects of boom length and spray droplet size on helicopter operations. The first component was a downwind spray deposition and drift study and the second component was an in-wind swath width study. Two helicopters, a Bell OH-58 (Bell Helicopter Textron, Inc., Fort Worth, Texas) and a Hiller UH-12E, (Hiller Aircraft Corporation, Marina, California) were used in both study components. The spray mix was tap water plus 0.25% volume/volume Triton X-100 (VWR International, West Chester, Pennsylvania) plus 0.53 gm/L (2 gm/gal) Caracid Brilliant Flavine FFN fluorescent tracer (Carolina Color and Chemical Company, Charlotte, North Carolina) plus 1.85 gm/L (7 gm/gal) FD&C Blue #1 colorimetric tracer (Warner Jenkinson Company, Inc. [now Sensient Colors], St. Louis, Missouri). The fluorescent tracer was included for drift measurements and the colorimetric tracer was included for swath width measurements.

The study was conducted in early November 2001 at Buffalo Ranch, Burleson County, Texas. The original plan was to conduct the study with a split plot – on droplet size – randomized block arrangement of treatments in four replications, but because of management needs to get the Bell OH-58 back to gainful activity, the Bell OH-58 treatments were all applied first, split on droplet size, on November 6-7, and the Hiller UH-12E treatments were applied on November 13. The treatment setups are shown in table 1. The booms were front-toe-mount on both aircraft. Both the Accu-Flo (Bishop Equipment Manufacturing, Inc., Hatfield, Pennsylvania) and CP-03 (CP Products Company, Inc., Tempe, Arizona) nozzles were mounted on 25 cm drops and oriented straight back or horizontally with the airflow, figure 1. The Accu-Flo and CP-03 nozzles were switched to the same boom positions for the respective treatments.

Table 1. Eight treatment setups for the spray drift and swath width study.

Helicopter	Boom/Rotor, %	Droplet Size, $D_{V0.5}$	Nozzle* Number and Identification
Hiller UH-12E	100%	1000 µm	33 Accu-Flo 0.028$^{\otimes}$ 64 Tube
Bell OH-58	100%	1000 µm	33 Accu-Flo 0.028$^{\otimes}$ 64 Tube
Hiller UH-12E	75%	1000 µm	25 Accu-Flo 0.028$^{\otimes}$ 64 Tube
Bell OH-58	75%	1000 µm	25 Accu-Flo 0.028$^{\otimes}$ 64 Tube
Hiller UH-12E	100%	400 µm	33 CP-03 0.078$^{\otimes}$ 55°$^{\phi}$
Bell OH-58	100%	400 µm	33 CP-03 0.078$^{\otimes}$ 55°$^{\phi}$
Hiller UH-12E	75%	400 µm	25 CP-03 0.078$^{\otimes}$ 55°$^{\phi}$
Bell OH-58	75%	400 µm	25 CP-03 0.078$^{\otimes}$ 55°$^{\phi}$

* Nozzles were mounted on drop booms 25 cm below the boom; longitudinal axes of the nozzles were nominally parallel to the airstream. Accu-Flo nozzles had a D6 restrictor.
$^{\otimes}$ Orifice size
$^{\phi}$ Deflector angle

All treatments were applied in nominal crosswind with helicopter airspeed of 97 km/h (60 mph) and spray pressure of 345 kPa (50 psi). Treatment droplet sizes were based on wind tunnel studies with the nozzle and application parameters as specified (Kirk, 2002). Pilots were advised to maintain boom height at 3 m (10 ft). Effort was made to apply all treatments in wind speeds of 1.8-4.5 m/s (4-10 mph). A weather station was placed upwind and adjacent to the swath and spray drift sample line. Wind speed and direction, temperature, and relative humidity were recorded at 0.3-, 2-, 4-, and 10-m heights. Swath widths were set at 1.5X boom length with spray rate of 56 L/ha (6 gpa). Two spray swaths, one with the left wing on the upwind side and one with the right wing on the upwind side, were flown over a marked swath line to constitute a total swath treatment application of 112 L/ha (12 gpa). The field used for the study was in cotton the previous season and had been chiseled and disked before the study was conducted. The field layout is shown in figure 2. The spray swaths were marked perpendicular to prevailing wind directions and the spray deposition and drift lines were established downwind

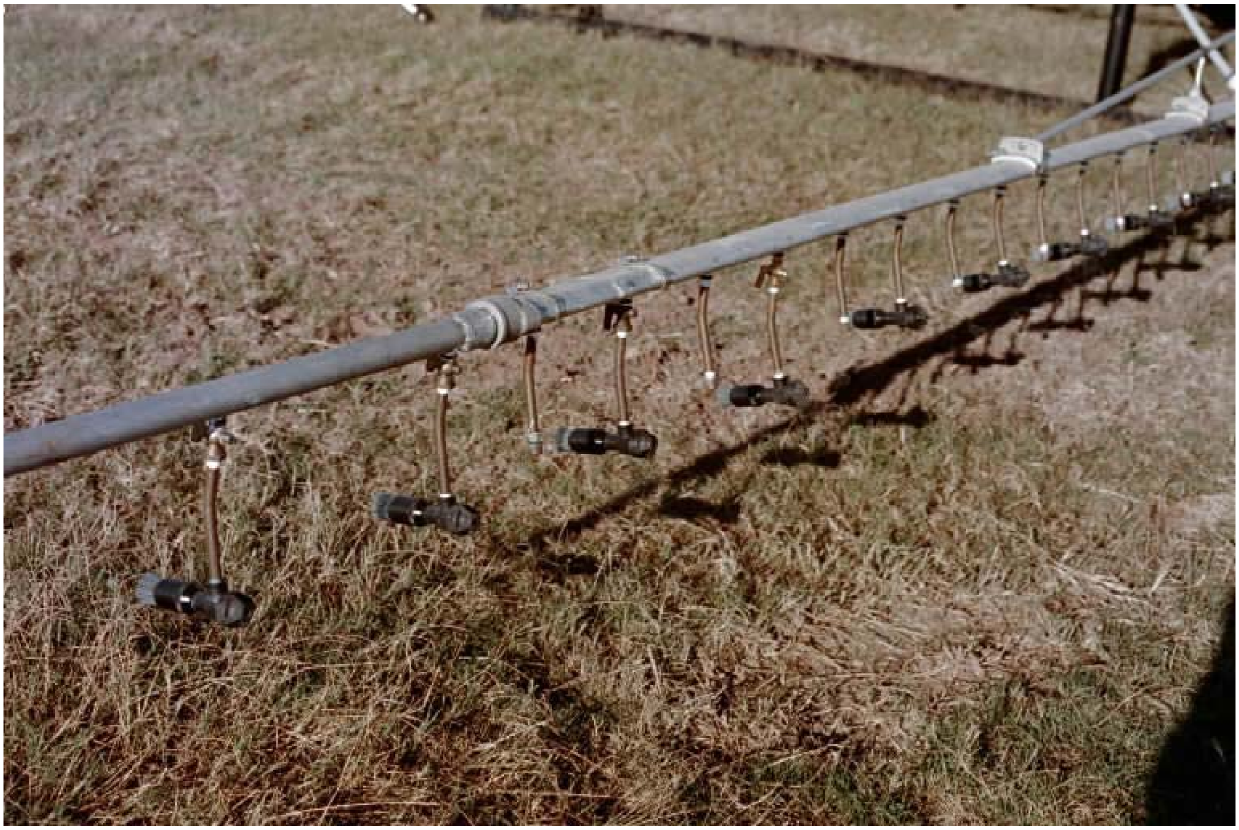

Figure 1. Accu-Flo nozzle and boom setup on Hiller UH-12E. (Note the boom extension and the cut-offs for converting from 100% to 75% effective boom length.)

and parallel to these prevailing wind directions at the mid-point of the spray swaths. The in-swath sample locations were -S12, -S9, -S6, -S3, and S0 for the 75% boom length treatments and –S16, -S12, -S8, -S4, and S0 for the 100% boom length treatments (spray swath sample locations measured in meters from the downwind edge of the spray swath). The downwind sample locations were D2.5, D5, D10, D20, D40, D80, D160, and D320 (drift sample locations measured in meters from the downwind edge of the spray swath). Each sample location had a 10- X 10-cm mylar card and a 24- X 76-mm water-sensitive paper (WSP) sampler (WSP only on Replication 1) (Spraying Systems Co., Wheaton, Illinois). These two sample collectors were located on a 30- X 30-cm plywood sheet placed on the plowed ground. Mylar card collectors and stable fluorescent tracers give good estimates of spray swath and drift deposits on planar surfaces. The WSP samples were removed from the sample line after one pass of the helicopter. The mylar cards were placed and collected after two passes of the helicopter for each treatment for the four replications.

Spray and drift deposits were determined by procedures used in previous studies (Kirk et al., 2000). The mylar cards were placed in individual plastic bags and washed in 20 ml of ethanol. An aliquot of effluent was placed in 12- X 75-mm borosilicate glass culture tubes and fluorometric dye concentrations were obtained with a Shimadzu RF5000U

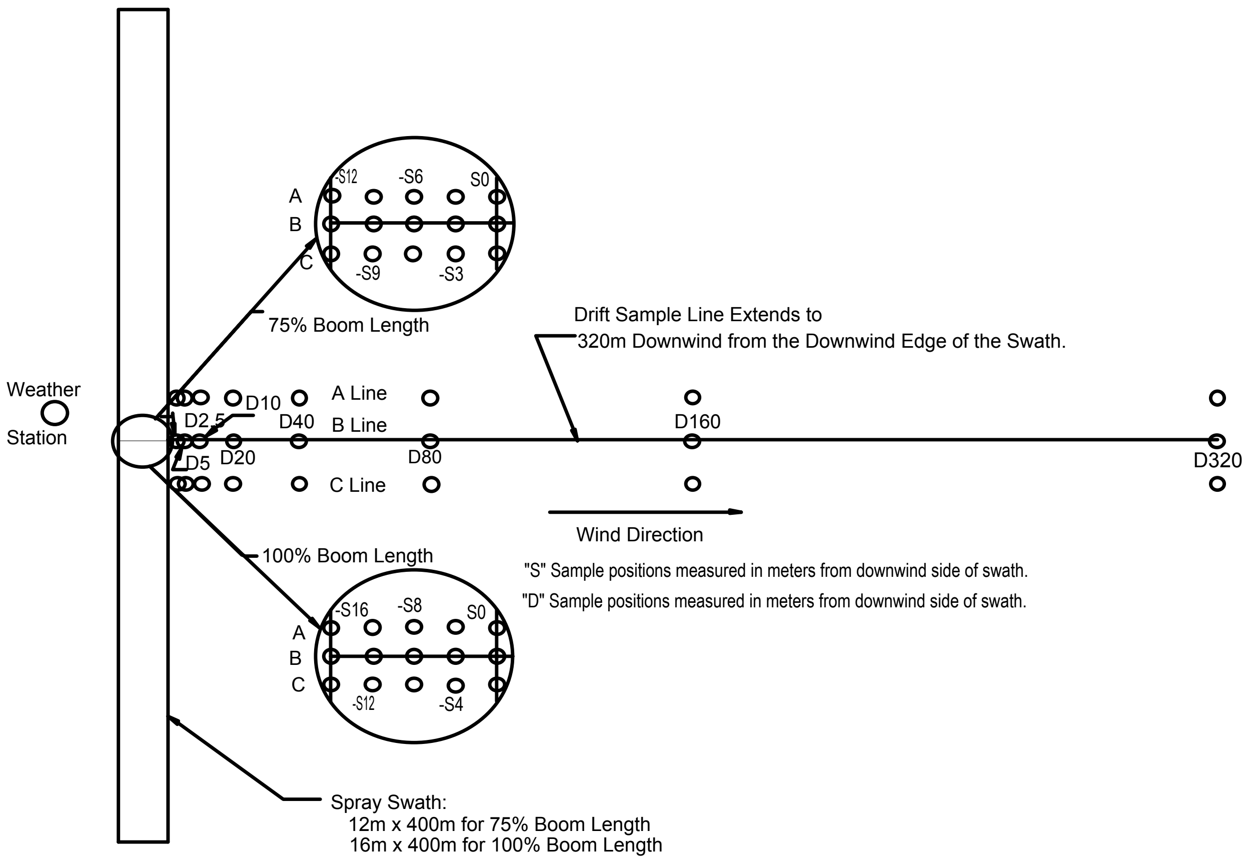

Figure 2. Field layout for helicopter boom length and spray droplet size study.

Spectrofluorophotometer (Shimadzu Corporation, Kyoto, Japan). Spray deposits on the cards were quantified by comparison with similarly determined dye concentrations from spray tank samples. The mylar card data quantifications are expressed as quantity of dye deposited per unit area of the card. This analysis gives a relative deposit comparable to the amount of a pesticide active ingredient deposited per unit area. The WSP samples were placed in 35-mm negative sleeves and processed with computerized image analysis (IMAQ Vision Builder v5, National Instruments, Austin, Texas) to determine droplet stain density and stain size. Stain size, stain diameter, or minimum stain dimension (D_s in µm) was determined for each stain in two 1.5 cm^2 sample areas on each card. Each stain in the sample area was converted to droplet diameter (D_d in µm) with the experimentally determined equation for a spray mix of tap water plus 0.25% v/v Triton X-100:

$$D_d = 0.535\ D_s - 8.484E\text{-}05\ D_s^2$$

Percent coverage, droplet density, and droplet size were subsequently determined for each WSP card.

The swath width data collections for each helicopter were made with an automated swath deposit and analysis system similar to those described by Carlton and Bouse (1988) and Carlton et al. (1990). The helicopters were each flown in-wind over a suspended monofilament collection line in four replications. Pilots were advised to maintain boom height at 3 m as in the deposition and drift study. The spray mix was the same as used in the deposition and drift study. After a single spray pass, the monofilament line was drawn through a methanol wash cell with continuous colorimetric recording of the cell effluent with position on the line. These data were processed to give continuous recordings of effluent concentration vs. line or swath position.

Statistical analyses of the data were conducted with SAS STAT procedures (SAS 2001). The mylar card data were analyzed as repeated measures by distance using the Mixed procedure. The wind vector parallel to the sampling line was used as a covariate to account for deviation in wind velocity and direction for each treatment replication. The WSP data were analyzed by the General Linear Model procedure. Treatment differences were assessed by Fisher's F or Student's t as appropriate. Significance levels are stated with the data presentations.

Results and Discussion

Weather Conditions

This study was conducted under relatively consistent temperature conditions, averaging 25.7°C (78°F) with standard deviation of 0.5°C. Relative humidity ranged from 29% to 62%. Wind speed and direction varied widely. Five-minute averages at the 2 m (6 ft) height when the two spray swaths were made for each treatment replication ranged from 6 to 16 km/h (4 to 10 mph) with deviations from parallel with the spray sample line ranging from –22° to +27°, both after deletion of the four treatment replications with deviations >±30° according to ASAE Standard S561 JUN98 (ASAE Standards, 2000). Two treatments had three remaining replications; and one treatment had two remaining replications.

Spray Deposition and Drift

Mylar Card collections of spray and drift deposits, averaged by treatment for each sampler location, are shown in table 2. Graphical display of these data is helpful in better understanding the treatment responses. However the range of spray deposits, within the spray swath to far-field drift deposits, is so wide that a single graphical display of the data does not show differences that exist between treatments. Deposits in the spray swath and immediately beyond – the displaced swath – are shown in figure 3. It is apparent that the crosswind moved the spray deposit pattern downwind, which would be designated as a swath displacement of about ¼-swath in this case. It is also apparent that the designated swath width of 1.5 times boom length is a reasonable selection for effective swath width for the treatments in this study. There is considerable variability in the spray deposits in the swath from treatment to treatment, but other consistent treatment patterns are not readily apparent from deposits on the mylar card samplers. Further analyses and discussion of swath width will be made based on the in-wind swath width sampling on monofilament line.

Table 2. Spray and drift deposits (µg/cm^2) on mylar cards for the eight treatments at thirteen sampler locations.

*Aircraft-Boom Length-Droplet Size	-S16	-S12	-S9	-S8	-S6	-S4	-S3	S0	D2.5	D5	D10	D20	D40	D80	D160	D320
H-100 -1000	0.0004	0.22		0.76		0.59		0.46	.030	0.11	0.012	0.003	0.001	0.0003	0.0005	0.0005
B-100-1000	0.002	0.31		0.55		0.54		0.30	0.21	0.06	0.008	0.003	0.0007	0.0002	0.0001	0.0001
H-75-1000		0.0004	0.001		0.72		0.51	0.52	0.38	0.08	0.011	0.002	0.0003	0.0002	0.0001	0.0003
B-75-1000		0.0006	0.236		0.56		0.68	0.56	0.29	0.14	0.010	0.002	0.0004	0.0002	0.0001	0.0001
H-100-400	0.0002	0.28		0.58		0.46		0.34	0.17	0.07	0.028	.0095	0.0024	0.0013	0.0002	0.0001
B-100-400	0.0041	0.55		0.65		0.53		0.32	0.19	0.11	0.037	.0143	0.0056	0.0017	0.0003	0.0001
H-75-400		0.0006	0.102		0.57		0.43	0.46	0.22	0.08	0.028	.0065	0.0015	0.0004	0.0002	0.0001
B-75-400		0.0005	0.252		0.49		0.45	0.41	0.19	0.09	0.019	.0049	0.0013	0.0002	0.0001	0.0001

*Aircraft: H = Hiller UH-12E, B = Bell OH-58; Boom Length: 100 = 100% of rotor diameter, 75 = 75% of rotor diameter; Droplet Size: 1000 = 1000 µm $D_{V0.5}$, 400 = 400 µm $D_{V0.5}$.

The interactive effects of boom length and droplet size are active at both the D2.5 and D5 sample locations, but at D10 and beyond, the treatment effects are consistent. Consequently, the analyses of deposits on mylar cards will be made in the range of 10 to 320 m downwind of the downwind edge of the swath.

Statistical analyses of the drift deposits at D10 and beyond show no significant differences between helicopters $(p > F) = 0.26$. The two helicopters were included to broaden the scope of inferences that could be made from the study rather than to analyze any differences that could be observed between the two aircraft. Accordingly, the drift deposits will be analyzed and presented based on the boom length and droplet size variables with data combined for the two aircraft. These data will be shown separately in the near-field downwind (5 to 20 m from the downwind edge of the swath) and the far-field downwind (20 to 320 m from the downwind edge of the swath). The spray deposits on mylar cards in the near-field downwind are shown in figure 4 and the deposits in the far-field are shown in figure 5. The 400 µm diameter droplets had significantly higher downwind drift deposits than the 1000 µm diameter droplets $(p > F) \leq 0.01$. The 100 % boom length had significantly higher downwind drift deposits than the 75% boom length $(p > F) \leq 0.01$. In the range of the variables included in this study, droplet size had more effect on drift deposits than boom length.

Drift deposits for all treatments at 160 and 320 m downwind of the downwind edge of the swath were at the lower end of the detectable range with the tracer rate and procedures used in the study.

Water Sensitive Paper (WSP) sample data are generally less reliable in quantifying deposit parameters than mylar cards, primarily because sample sizes are significantly smaller and small experimental errors are magnified in calculated projections to leaf or field surfaces. However, there are certain parameters that are quantifiable on WSP that are not quantifiable on mylar cards. Data for these parameters are presented in table 3. Since there was no difference

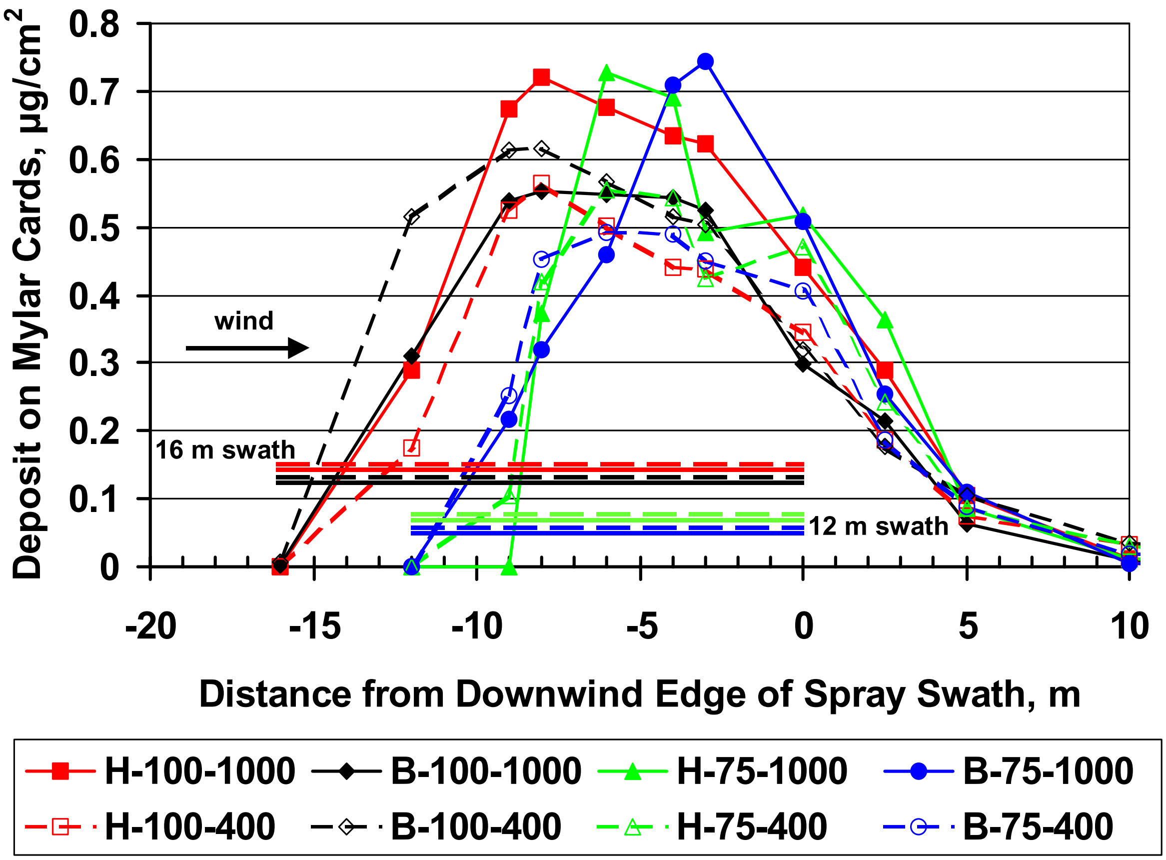

Figure 3. Swath and displaced swath spray deposits for eight treatments. The locations of the intended spray swaths for the respective treatments are indicated by the solid and dashed horizontal bars.

between the two helicopters in the downwind drift deposits on mylar cards, these data are presented without reference to the aircraft variable. Deposits were not detectable on WSP at S0, D80 (except for the 100% boom length – 400 μm droplet size treatment), D160, and D320.

Percent Coverage

The percent of the WSP card area covered with spray droplet stains (percent coverage) was variable by location in the swath and downwind. Only at D20 did the statistical analyses show significant differences due to boom length and droplet size effects; both the 100% boom length and 400 μm droplets had significantly higher drift deposits than the 75% boom length and 1000 μm droplets, respectively ($p > |t|) \le 0.05$. A similar trend can be observed in the data from the D10 and D40 sample locations, but the differences were not statistically significant.

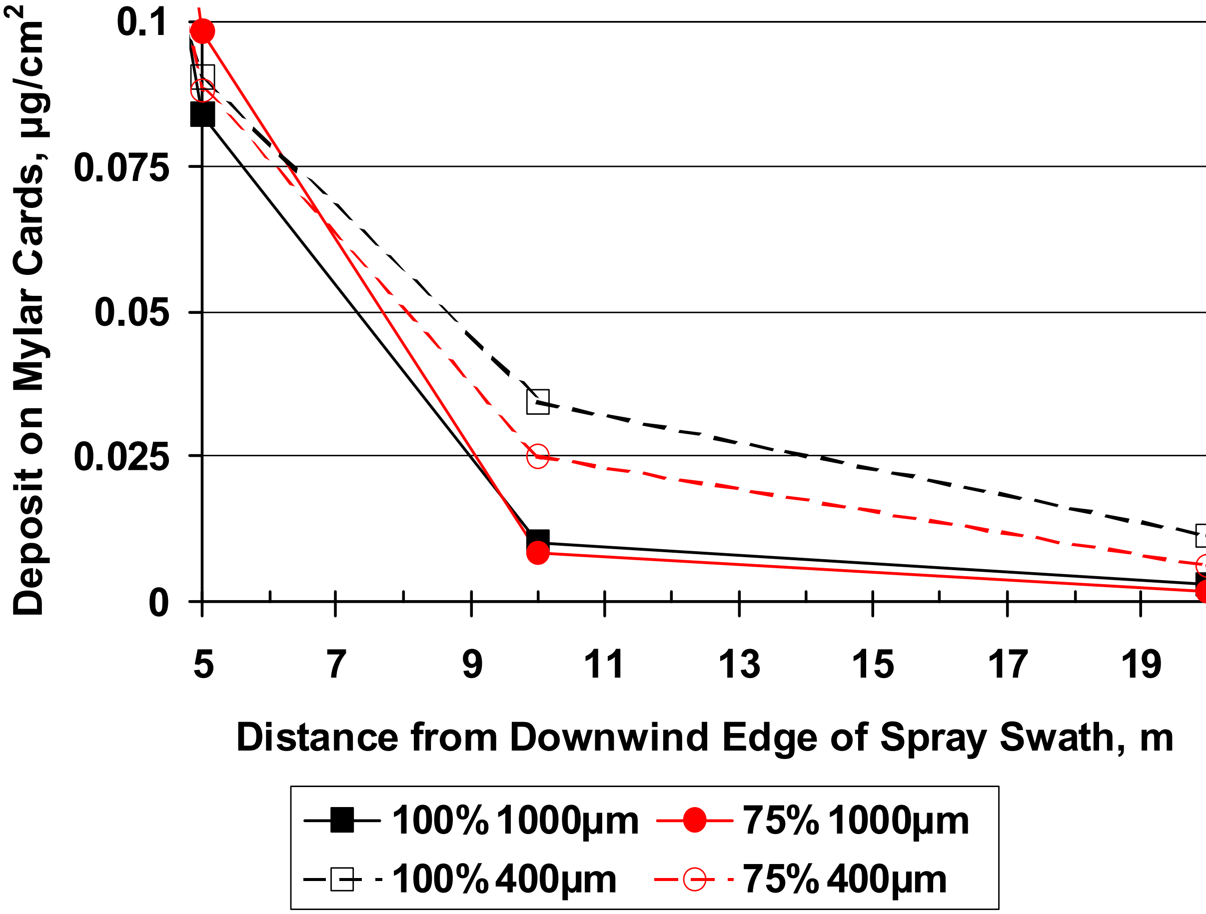

Figure 4. Near-field downwind spray drift deposits.

Droplet Density

The number of spray droplets per unit area were higher for the 400 µm droplet size than for the 1000 µm droplet size treatments at all downwind sample locations ($p > |t|) \leq 0.08$, indicating more droplets depositing downwind from the smaller droplet size sprays. The 75% boom length gave significantly lower droplet densities than the 100% boom length at sample location D20 ($p > |t|) \leq 0.05$.

Droplet Size

Spray droplet size computed from stains on WSP was higher at mid-swath for the specified 1000 µm than the 400 µm treatments, as would be expected. However, the values computed from the droplet stains on WSP were lower than estimated for the 1000 µm treatment and higher than estimated for the 400 µm droplet size treatments. Droplet sizes decreased at successive downwind sample locations and the difference between the droplet size treatments

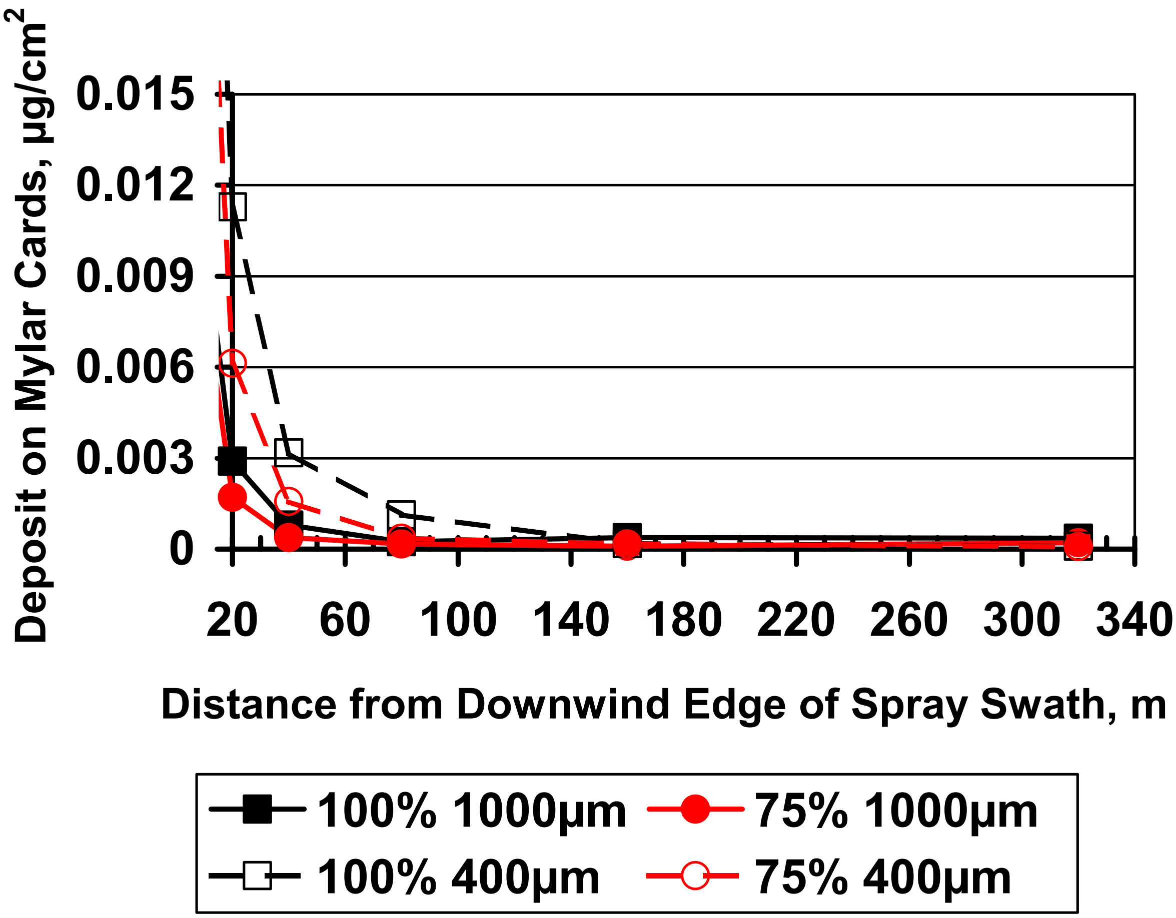

Figure 5. Far-field downwind spray drift deposits.

was significant to and including the D10 location ($p > |t|) \leq 0.10$. There was no significant difference between deposited droplet sizes for the droplet size treatments at downwind sample location D20 and beyond ($p > |t|) = 0.16$. The 100% boom length has larger droplet sizes than the 75% boom length for the downwind D10 through D40 sample locations ($p > |t|) \leq 0.11$, indicating the 100% boom length results in larger droplet sizes being entrained and depositing downwind.

Swath Width

Swath widths for the helicopters in this study were set by the operator-experience guide rule of 1.5 times boom length. Since there is an operational efficiency factor associated with reduced swath width from using this rule, we considered it appropriate to also evaluate swath widths with an automated swath pattern analysis system similar to the more familiar Operation SAFE procedure (Anon., ca. 2000). No attempt was made to improve the uniformity of within-swath deposition as is usually the case with these types of analyses. The purpose was only to assess the effects of droplet size and boom length on effective swath width. A typical swath deposition pattern is shown in figure 6.

Table 3. Spray and drift deposit data from stains on water sensitive paper for the four boom length and droplet size treatments at the swath and downwind sample locations.

*Boom Length -Droplet Size	S0	S3	S4	S6	S8	S9	S12	S16	D2.5	D5	D10	D20	D40	D>80
Percent Coverage														
100-1000	0		8.00		25.81		25.32	29.58	19.47	10.19	1.19	0.42	0.06	0
75-1000	0	1.81		26.16		18.33	10.73		21.58	12.78	1.65	0.11	0.01	0
100-400	0		6.07		33.56		30.91	19.95	19.49	14.66	3.35	2.63	0.54	0
75-400	0	10.21		21.05		22.89	22.59		14.64	13.45	2.59	0.53	0.24	0
Droplet Density, number / cm^2														
100-1000	0		1.99		9.61		12.59	6.96	12.59	6.96	5.63	3.31	0.99	0
75-1000	0	0.33		15.24		14.90	12.92		19.87	19.54	6.29	1.99	0.33	0
100-400	0		6.29		41.40		90.42	68.23	60.61	45.05	26.83	19.54	6.29	0
75-400	0	6.62		84.46		43.39	59.95		55.31	65.91	25.83	8.28	4.97	0
Droplet Size ($D_{V0.5}$), µm														
100-1000	0		417		741		685	736	647	518	244	164	144	0
75-1000	0	422		788		727	640		676	441	222	135	43	0
100-400	0		297		568		519	413	340	294	221	219	156	0
75-400	0	687		457		572	482		278	265	194	158	137	0

* Boom Length: 100 = 100% of rotor diameter, 75 = 75% of rotor diameter; Droplet Size: 1000 = 1000 µm $D_{V0.5}$, 400 = 400 µm $D_{V0.5}$.

A computerized single-swath lapping procedure is used in Operation SAFE procedures to overlap the swaths for optimum swath width, generally based on a low or minimum overall coefficient of variation (CV) at a reasonable swath width as a measure of uniform spray deposition across multiple swaths. These analyses coupled with experience and judgment are generally the bases of recommended swath widths from Operation SAFE procedures. These analyses with similar procedures indicated that there was no significant difference between these two helicopters relative to the swath width that they produced when equipped with identical boom and nozzle setups ($p > |t|$) = 0.13). Swath widths were significantly different for the 75% and 100% boom/rotor lengths ($p > |t|$) ≤ 0.01. The swath widths for the two boom lengths were 11.4 m (37.6 ft) and 15.7 m (51.7 ft) for the 75% and 100% boom/rotor lengths, respectively, compared to the guide rule of 12 and 16 m respectively. This analysis confirms the guide rule for both boom lengths as used to set swath width for helicopters for these droplet sizes at 1.5 times boom length. The analyses based on minimum CV at a reasonable swath width indicated that droplet size was not a significant factor in determining swath width with the droplet sizes used in this study ($p > |t|$) = .20. These separate analyses of in-wind swath width also confirm the observations about reasonable swath width noted and briefly mentioned from figure 3 which shows crosswind deposits on mylar cards from these aircraft.

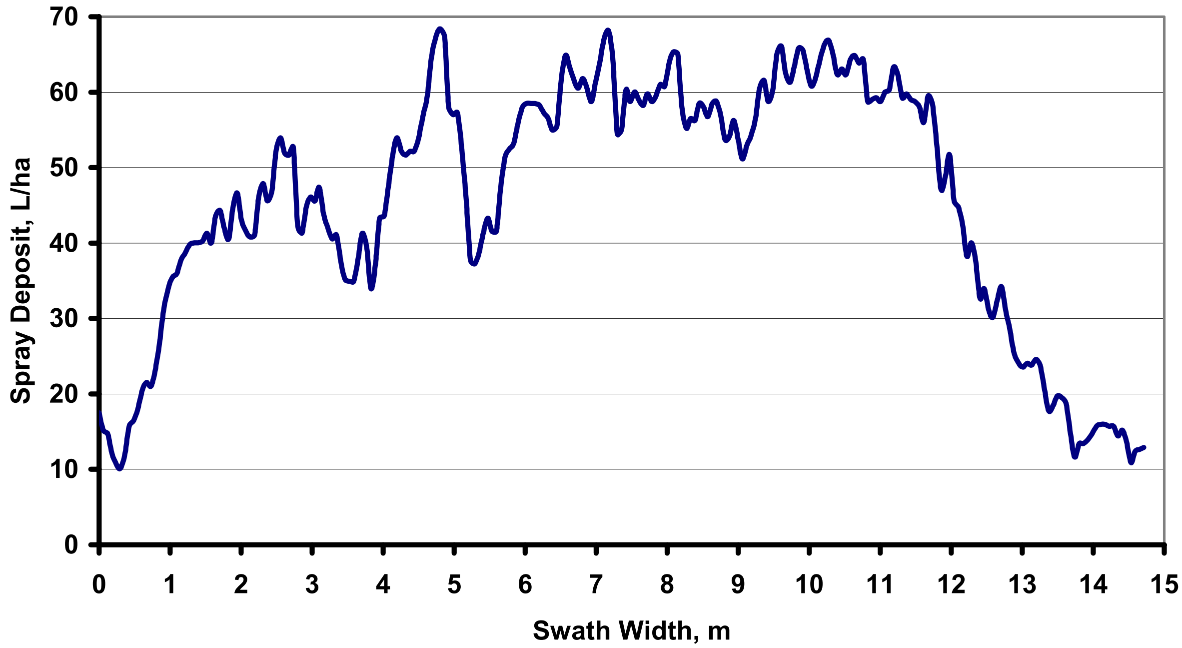

Figure 6. In-wind single-swath deposition pattern for a Hiller UH-12E with 75% boom/rotor length and Accu-Flo nozzles as used in this study.

Summary

This field study was conducted to determine influences of boom length and spray droplet size on effective swath width and spray drift from helicopters. Hiller UH-12E and Bell OH-58 helicopters were used in the study, but there was no difference between the two aircraft on in-swath and downwind spray and drift deposits when they were equipped with identical boom and nozzle setups and operated under the same conditions. Boom lengths of 75% and 100% of rotor diameter and droplet sizes of 400 µm (Medium (M) spray with 2.5% of spray volume in droplets less than 100 µm diameter) and 1000 µm (Extremely Coarse (XC) spray with 0.5 % of spray volume in droplets less than 100 µm diameter) were used for treatment conditions. Results of the study show that boom lengths of 75% reduce effective swath width when compared to 100%, for the droplet sizes and operating conditions of this study. But the 100% boom length results in increased downwind drift deposits. The XC droplet spectrum reduces downwind spray drift and deposition, compared to the M droplet spectrum. This study provides helicopter operators with operational guidelines for boom length and spray droplet size to optimize swath width and mitigate spray drift from helicopter applications of crop production and protection products.

Acknowledgments

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